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CHART OF PROPERTIES OF MINE GASES

Compiled by
G. A. BURRELL

PHYSIOLOGICAL EFFECTS OF DIFFERENT GASES ON MAN.

OXYGEN.[a]

The breathing, in some persons, is affected when the proportion of oxygen in the air breathed drops to 13 per cent. With 10 per cent the breathing is distinctly deeper and lips slightly bluish; with 7 per cent life is endangered and unconsciousness soon follows.[b] (See fig. 1.) In coal mines low-oxygen atmosphere means that the ventilation is poor. Coal reacts with the oxygen of air in mines, and sometimes absorbs and holds it to such an extent that the residual atmosphere does not contain enough oxygen to support life.

Effect	Oxygen in air, per cent (0–12)
Fatal	7
Slight distress	13

FIG. 1—Effect on man of lowering the proportion of oxygen in the air breathed.

[a] From experiments by the author.
[b] These statements refer to persons at sea level or thereabouts who suddenly enter low-oxygen atmospheres. By acclimatization man becomes accustomed to low-oxygen atmospheres; for instance, men live at altitudes of 12,000 feet or higher where the percentage of oxygen by volume is equivalent to air at sea level that contains 13 per cent of oxygen.

CARBON MONOXIDE.[a]

Carbon monoxide is colorless, odorless, and tasteless, and is very poisonous; 0.05 per cent carbon monoxide is sufficient to produce in time slight symptoms of poisoning; 0.12 per cent may produce slight palpitation of the heart in 30 minutes, tendency to stagger in 1½ hours, and impair sight and hearing, confusion of mind, headache, and sickness, in 2 hours; 0.2 per cent is very dangerous to man. (See fig. 2.) Exposure for 20 minutes to air containing 0.25 per cent may bring on nausea and headache lasting 12 hours. Canaries collapse in atmospheres containing 0.15 per cent carbon monoxide in 18 minutes, and show distress in 3 minutes; hence they can be used to warn men of carbon monoxide. The gas may be present in deadly proportions in an atmosphere that a miner's lamp will burn in, so that the lamp gives no warning of its presence.

[a] From experiments by the author.

Gas	Effect of gas	Gas in air, per cent (0–8)
Carbon dioxide	Distress begins	3
	Distress is great	10
Carbon monoxide	Slight symptoms of poisoning	0.05
	Dangerous	0.2
Hydrogen sulphide Nitrogen peroxide Sulphur dioxide	(Immediate distress in canaries and mice)	0.05

FIG. 2—Effect of noxious gases on man.

HYDROGEN SULPHIDE, NITROGEN OXIDE, AND SULPHUR DIOXIDE.[a]

These three gases are all harmful to men even in very small proportions. Proportions as small as 0.05 per cent (See fig. 2) produce almost immediate distress in canaries and mice.

[a] From experiments by the author.

METHOD FOR REVIVING A MAN OVERCOME BY GAS.

If a man is overcome by bad air, powder smoke, afterdamp, or the like, first move him to fresh air, then loosen his clothing. Open his collar and place him face downward on a blanket, brattice cloth, or coat spread on the floor. One of his hands should be held straight out beyond his head, the other placed under his head. His head should be turned to one side and his tongue pulled forward, any tobacco, gum, false teeth, or the like being removed from his mouth. Put a folded jumper or coat under lower part of his chest if he is thin; straddle him on your knees, facing his head (see fig. 3) and with your knees a little below his

FIG. 3.—Schaefer method of artificial respiration (inspiration.)

FIG. 4.—Schaefer method of artificial respiration (exhalation).

hips; then with fingers outstretched place your hands at the lower part of his ribs with your thumbs nearly joining; then press downward and inward; then take hands and pressure off slowly, keeping hands in place (see figs. 3 and 4); again, with outstretched hands as before, press downward and inward, and so on, about 16 to 20 times every minute. Keep this up for at least three hours if he does not start to breathe sooner. When he starts to breathe, keep him warm by covering with coats, jumpers, blankets, or the like, or use covered safety lamps, hot-water bottles, or hot bricks, until the doctor comes, but do not give brandy, whisky, coffee, or any other food or drink unless he is able to talk and drink, then give one teaspoonful of aromatic spirits of ammonia in half a glass of water or hot coffee slowly. When he starts to breathe, try to make him vomit by tickling the back of his throat or by putting your finger down his throat. Never attempt to give an unconscious man anything to drink, as the liquid will choke him. This same treatment should also be used for a man overcome by electric shock.

METHANE.

Methane has no physiological effect when breathed, but may render air unfit to breathe by diluting it until the proportion of oxygen is too low. This gas is very explosive in mixture with air, and because of the quantities in which it is formed is the most dangerous gas generated in mines.

CARBON DIOXIDE.[a]

Carbon dioxide does not usually cause distress in man until 3 to 4 per cent of carbon dioxide is present in the air, when the breathing becomes affected. Men may work for a considerable time in such an atmosphere, but are more quickly fatigued; 7 to 8 per cent causes more urgent symptoms; 10 per cent causes marked distress, severe headache, heavy panting, throbbing of the heart, and flushing of the face, and stupefaction. (See fig. 2.) Carbon dioxide stimulates the so-called "respiratory center" in the brain, and makes a person breath more air in a given time. As little as 1.4 per cent may cause an increase of 50 per cent in volume of air breathed. This deeper breathing consumes energy, just as work does, and limits the amount of work a man can do, in proportion to the amount of carbon dioxide breathed. Breathing a large percentage of carbon dioxide produces a poisonous action because the carbon dioxide in the air breathed prevents the blood from giving off carbon dioxide.

[a] From experiments by J. J. Haldane and Lorain Smith, England. Also corroborated by experiments of the author.

NITROGEN.

Nitrogen is physiologically inert, and is harmless to man. It has no effect other than to act as a diluent of the oxygen in air.

EFFECT OF WARM, MOIST, AND STILL AIR ON MAN.

A hot, moist atmosphere prevents the evaporation of perspiration. If the hot, moist air is stationary, it becomes entangled between the clothing and the skin and becomes warmed to body temperature. Hence the body can not lose heat to the air and the skin becomes warm, flushed, and bathed in perspiration. Setting the air in motion by a fan whirls the hot air away from the body and allows cooler air to take its place; hence the beneficial effects of a fan in a room even if fresh outside air can not enter. If the wet-bulb temperature of the air is the same as that of the body, 99° F., the body can not lose heat, but if the air temperature is about 70° F. perspiration can evaporate. Above 75° F., wet-bulb temperature, the amount of work a man can do begins to fall off. Between 80° F. and 85° F., wet-bulb temperature, hard continuous work is almost impossible. Wet-bulb temperatures are determined with a sling psychrometer.

SOURCES OF DIFFERENT GASES IN MINES.

OXYGEN AND NITROGEN.

The oxygen and nitrogen in mine air come from the atmospheric air. Nitrogen to a minor extent transpires from the coal.

CARBON DIOXIDE.

Most of the carbon dioxide found in coal mines comes from the coal, escaping continuously from the pores and crevices of the coal as it is broken down. Some carbon dioxide is formed by the action of air on the carbon of the coal and the timbers. Some carbon dioxide is added to the air and oxygen taken from it by the breathing of men and animals, by the burning of lamps, and burning of blasting powder.

CARBON MONOXIDE.

Carbon monoxide is not a normal constituent of mine air except possibly in harmless traces. It is produced in mines by the incomplete combustion of gas and of coal dust in explosions and mine fires, and by the burning of wood and coal with insufficient oxygen. It is also produced by the firing of blasting explosives, and by the contact of previously formed carbon dioxide with red-hot carbon, as when the flame of a blast or a gas explosion is projected into an atmosphere filled with fine coal dust.

METHANE.

Methane, known to miners as "fire damp" or "gas," is colorless, odorless, and tasteless. It is constantly given off in most coal mines and forms explosive mixtures with air, so that its detection and removal are essential to safety. Methane is the product of the decomposition of vegetable matter under water and superimposed strata. It transpires from the pores and openings in the coal, especially from freshly exposed coal; it may issue from the floor or roof of the coal bed if the adjacent strata are more pervious than the coal. It may transpire from the entire face or issue in a strong flow as a blower or feeder.

BLACK DAMP.

When outside air enters a coal mine, some oxygen is absorbed and some carbon dioxide is given off by the coal. When oxygen is taken away from the air of a room, the "air" then contains less oxygen and more nitrogen than ordinary air. A mixture of this excess nitrogen with the carbon dioxide that comes from the coal constitutes black damp. It is the lack of oxygen in mixtures containing black damp that is responsible for most of the effects of such atmospheres on the health of men and the burning of lights, although carbon dioxide also contributes. The average composition of black damp is 11 per cent carbon dioxide and 89 per cent nitrogen.

DETECTION OF GASES IN MINES.

Dangerous amounts of methane are shown by the cap on a safety lamp. (See fig. 5.)

Low-oxygen atmospheres are shown by the flame of a lamp. Below about 17 per cent of oxygen an oil-fed flame is extinguished; below about 13 per cent of oxygen the acetylene flame is extinguished.

Carbon monoxide can be detected if a canary is carried into the mine.

Hydrogen sulphide is detected by its odor.

There is little danger of a mine-rescue squad unknowingly entering dangerous atmospheres if they carefully watch the burning of their safety lamps and carry a canary.

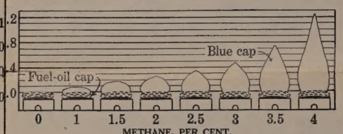

FIG. 5.—Height of cap on safety-lamp flame corresponding approximately to different percentages of methane.

HYDROGEN.

Hydrogen is formed in mines in much the same way that carbon monoxide is—by incomplete combustion in explosions, mine fires, and firing of blasting explosives—but in much smaller quantity.

AFTERDAMP.

Afterdamp is the term commonly applied to gases produced by explosions and mine fires. Oxygen, carbon dioxide, methane, carbon monoxide, nitrogen, water vapor, sulphurous acid, hydrogen sulphide, and smoke are found in afterdamp; small amounts of creosote and benzol and other products of heating coal are also formed and are largely responsible for the characteristic odor. Oxygen, carbon dioxide, nitrogen, water vapor, and usually some methane are present before an explosion or mine fire.

HYDROGEN SULPHIDE, SULPHUR DIOXIDE, AND NITROGEN PEROXIDE.

All of these gases may be formed from the burning of blasting powder. Hydrogen sulphide is formed in considerable quantity from black blasting powder; sulphur dioxide in traces only, and nitrogen peroxide in traces usually, but sometimes in considerable quantity by the improper burning of explosives. Hydrogen sulphide rarely is found naturally occurring in mines but sometimes is dissolved in water therein. The stirring of a pool of such water causes the water to give up the gas readily.

PROPERTIES OF GASES IN MINES.

COMPILED BY G. A. BURRELL, BUREAU OF MINES.

CHEMICAL PROPERTIES OF GASES FOUND IN COAL MINES.

Name.	Formula.	Miner's term.	Specific gravity (Air = 1.)	Molecular weight.	Ignition temperature. °C.	Ignition temperature. °F.	Weight of gas, pound per cubic foot, at 0°C. and 760 mm. pressure.	Boiling point, °C.	Critical data.[a] Temperature, °C.	Critical data.[a] Pressure, atmospheric.	Relative rates of diffusion (Air = 1.)
Air	([b])		1.000				0.08071	About −190			1.000
Oxygen	O_2		1.1054	32.00			.08922	−183	−118	50	.9487
Nitrogen	N_2	Black damp	.9672	28.02			.07812	−195	−146	35	1.0143
Carbon dioxide	CO_2	Black damp	1.5291	44.00			.12269	−78.5	31	73	.8120
Methane[c]	CH_4	Fire damp	.5545	16.03	650–750[d]	1100–1380	.04470	−160	−81.8	54.9	1.3440
Carbon monoxide	CO	White damp	.9672	28.00	650	1100	.07807	−190	−141.1	35.9	1.0149
Hydrogen sulphide	H_2S	Stink damp	1.1906	34.09			.09508	−62	100	90	.9500
Hydrogen	H_2		.0695	2.016	585	1050	.00562	−253	−241	15	3.830
Nitrogen peroxide	NO_2		2.65	46.01			.12347	+21	158	100	.81
Sulphur dioxide	SO_2		2.2638	64.07			.17862	−11	155.4	78.9	.67
Acetylene[e]	C_2H_2		.9056	26.02	About 450		.07254	−84	37.05	69	1.06
Ethane[f]	C_2H_6		1.0494	30.05	520–630	970–1170	.08470	−89.3	35.5	61.6	.983

[a] Gases can not be liquefied, no matter what the pressure, when above a certain temperature, characteristic of each gas, called the critical temperature. The pressure at which liquefaction takes place, when the critical temperature is reached, is called the critical pressure.
[b] Pure dry air contains approximately 20.93 per cent O_2, 0.03 per cent CO_2, and 79.04 per cent N_2.
[c] Methane, also known as fire damp, is constantly being given off in most coal mines, and is highly explosive in mixture with air.
[d] Methane ignites slowly at the ignition temperature, about 6 seconds being required to ignite it, but at about 950° C. ignition is instantaneous.
[e] From calcium carbide of miner's lamp; 1 pound of carbide produces practically 4.6 cubic feet of acetylene; the reaction is: $\{ CaC_2 + H_2O = C_2H_2 + CaO.$ $CaO + H_2O = Ca(OH)_2.$
[f] From natural gas that may leak into mines.
NOTE.—Ethylene (C_2H_4) occurs in mines in such small quantities, from fires, explosions, etc., that it need not be considered here.

COMPOSITION OF NATURAL GAS (PITTSBURGH).[a]

Gas.	Per cent.
Carbon dioxide (CO_2)	Trace
Methane (CH_4)	84.7
Ethane (C_2H_6)	9.4
Propane (C_3H_8)	3.0
Butane, etc. (C_4H_{10})	1.3
Nitrogen (N_2)	1.6
	100.0

[a] From analyses by the author.

COMPOSITION OF ATMOSPHERIC AIR.

Gas.	Per cent by volume.
Carbon dioxide (CO_2)	0.03
Oxygen (O_2)	20.93
Nitrogen (N_2)	79.04
	100.00

COMPOSITION OF ARTIFICIAL ILLUMINATING GAS (PITTSBURGH).[a]

Gas.	Per cent.
Carbon dioxide (CO_2)	2.6
Oxygen (O_2)	.8
Illuminants (C_2H_4, etc.)	8.7
Carbon monoxide (CO)	13.3
Hydrogen (H_2)	37.0
Methane (CH_4)	31.0
Ethane (C_2H_6)	1.8
Nitrogen (N_2)	4.8
	100.0

[a] From analyses by the author.

AVERAGE ANALYSIS OF RETURN AIR FROM ONE HUNDRED MINES IN THE UNITED STATES.[a]

Gas	Per cent
Carbon dioxide (CO_2)	0.18
Oxygen (O_2)	20.51
Methane (CH_4)	.20
Nitrogen (N_2)	79.11

[a] Determined by the author.

EXPLOSIVE LIMITS OF MIXTURES OF COMBUSTIBLE GASES AND AIR.[a]

Gas	Gas mixture in air, per cent
Gasoline vapor	1.5 to 6
Ethane	2.5 to 5
Methane	5.5 to 14.5
Natural gas	5 to 12
Acetylene	3 to 73
Artificial illuminating gas	7 to 21
Hydrogen	10 to 66
Carbon monoxide	15 to 73

FIG. 6.—Explosive limits of different gases.

Reactions with oxygen are:

Methane .... $CH_4 + 2O_2 = CO_2 + 2H_2O$
Ethane .... $C_2H_6 + 3.5O_2 = 2CO_2 + 3H_2O$
Hydrogen .... $2H_2 + O_2 = 2H_2O$
Carbon monoxide .... $2CO + O_2 = 2CO_2$
Acetylene .... $C_2H_2 + 2.5O_2 = 2CO_2 + H_2O$

[a] By explosive limits are meant the maximum and minimum percentages of a combustible gas in air, between which propagation of flame takes place through the mixture when ignited. These values were determined by the author. The artificial illuminating gas was made by the destructive distillation of coal.
NOTE.—In explosions of methane and air the flame travels fastest in mixtures containing 9.5 to 10 per cent of methane, at the rate of about 23 feet per second. The maximum pressure developed by explosion is about 115 pounds per square inch.

PERCENTAGE OF OXYGEN IN AIR BELOW WHICH FLAMES ARE EXTINGUISHED.[a]

Jet of flame	Point of extinguishment—Oxygen, per cent
Candle	16.5
Wolf lamp	16.5
Acetylene	13.0
Hydrogen	6.3
Carbon monoxide	13.4
Methane	15.6
Natural gas	14.0

FIG. 7.—Percentage of oxygen in air below which flames are extinguished.

Fig. 7 shows that the ordinary oil-fed flame is extinguished when the oxygen in mine air falls below 16 to 17 per cent, and the acetylene flame is extinguished when the oxygen becomes less than about 13 per cent.

[a] From experiments by the author.

EFFECT OF REDUCING THE OXYGEN CONTENT OF AIR ON FLAME ILLUMINATION.[a]

Oxygen Per cent	Light given off, per cent
18.0	
18.8	
19.3	
19.9	
20.3	
20.7	
21.0	

FIG. 8.—Amount of light given off by safety lamp as oxygen content of air is diminished.

Fig. 8 shows that even a slight reduction of the oxygen content of mine air causes a marked falling off in the illumination of lights. In making these experiments the illumination of a safety lamp was determined when the oxygen content in the air was normal, 20.93 per cent. Then the oxygen content in the air was gradually diminished and the illumination tested.

[a] From experiments by J. S. Haldane, in England.

EFFECT OF REDUCING THE OXYGEN CONTENT OF METHANE-AIR MIXTURES ON THE EXPLOSIBILITY OF METHANE.[a]

Oxygen Per cent	Explosive limit, per cent methane
21	5.5 to 14.5
18	5.7 to 12.8
17	5.7 to 11.8
16	5.8 to 10.7
15	5.9 to 10.1
14	6.2 to 8.2
13	6.3 to 7.1

FIG. 9.—Change in explosive limits of methane and air mixtures as the oxygen content of air is decreased.

Fig. 9 shows that oxygen is an important factor in reducing the explosibility of methane-air mixtures, but the oxygen has to fall below 13 per cent to make explosion impossible. The explosive limits of mixtures of methane and atmospheric air were first determined; next the methane was mixed with air that contained only 19 per cent oxygen, instead of 21, and the limits again determined, and so on.

[a] From experiments by J. K. Clement, Bureau of Mines.

EFFECT OF INCREASING THE CARBON-DIOXIDE CONTENT ON THE EXPLOSIBILITY OF METHANE-AIR MIXTURES.[a]

CO_2 Per cent	Explosive limit, per cent methane
0	5.5 to 14.5
20	6.4 to 12
38	7.2 to 10.8
50	8 to 10.3

FIG. 10.—Change in explosive limits of methane-air mixtures as the nitrogen is replaced by carbon dioxide.

In making these experiments the explosive limits of mixtures of methane and atmospheric air were first determined. Next different amounts of carbon dioxide were added and the limits again determined.

[a] From experiments by J. K. Clement, Bureau of Mines. In these experiments the oxygen content was kept constant at 19 per cent. Carbon dioxide has but little effect in changing the explosive limits. As much as 20 per cent only raises the low limit to 6.4 per cent.

CARBON DIOXIDE AND CARBON MONOXIDE IN EXHAUST GASES FROM GASOLINE MINE LOCOMOTIVE.[a]

Size of engine cylinder, inches.	Number of cylinders.	Speed, revolutions per minute.	Probable maximum amount of noxious gases, cubic feet per minute. Good carburation. CO.	Good carburation. CO_2.	Bad carburation. CO.	Bad carburation. CO_2.	Amount of air (cubic feet per minute) required to dilute exhaust gases to 1 part CO per 1,000 parts of air. Good carburation.	Bad carburation.
4.75 by 5.25	4	800	2.61	6.80	9.91	3.65	2,610	9,910
6 by 6	4	700	4.17	10.86	15.85	5.82	4,170	15,850
7 by 7	4	500	4.73	12.33	17.97	6.62	4,730	17,970

[a] From experiments by O. P. Hood and R. H. Kudlich, of the Bureau of Mines. Analyses by the author.
If a gasoline locomotive is to be operated in a mine without injuring the health of the miners, enough air must be circulated to dilute properly the exhaust gases.

TYPICAL ANALYSES OF THE GASES PRODUCED BY FIRING BLASTING EXPLOSIVES.[a]

Gas.	Black blasting powder.	Permissible explosives. Explosive giving the maximum amount of poisonous gases.	Permissible explosives. Explosive giving small amount of poisonous gases.	Black blasting powder.[b]	40 per cent straight nitroglycerin dynamite.[c]	40 per cent strength ammonia dynamite.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbon dioxide	19.2	26.7	30.3	49.7	27.3	41.4
Carbon monoxide	28.1	36.4	5.1	10.8	26.9	3.8
Oxygen	.0	.0	.0	.0	.0	.0
Hydrogen	10.0	14.2	.0	1.8	18.0	3.1
Methane	.6	1.4	.5	.6	.4	.8
Hydrogen sulphide	6.8	.0	.0	8.7		
Nitrogen	35.3	21.3	64.1	28.4	27.4	50.9
Total	100.0	100.0	100.0	100.0	100.0	100.0

[a] The first three analyses are by the author, the last three are by A. L. Hyde, Bureau of Mines.
[b] One pound of black blasting powder produces about 5.4 cubic feet of gas.
[c] One pound of 40 per cent straight nitroglycerin dynamite produces about 7 cubic feet of gas.

The first three analyses are of samples collected in the crevices of coal 20 seconds after firing the shot, calculated oxygen-free and methane-free according to Bichel-gage analyses. The last three analyses are of samples collected in a Bichel gage. In this gage the explosive was fired in an atmosphere devoid of oxygen, and the oxygen for combustion came from the explosive itself. These analyses show the poisonous gases given off when explosives are fired in coal mines and show also that miners must not advance to a working place too soon after firing a shot.

GASEOUS PRODUCTS FROM INCOMPLETE EXPLOSION OF MIXTURES OF METHANE AND AIR (AFTERDAMP FROM INCOMPLETELY BURNED METHANE).[a]

	Mixture containing 10 per cent CH_4.	Mixture containing 11 per cent CH_4.
	Per cent.	Per cent.
Carbon dioxide (CO_2)	10.2	8.4
Carbon monoxide (CO)	2.1	4.4
Hydrogen (H_2)	1.4	3.7
Nitrogen (N_2)	86.3	83.5
Total	100.0	100.0

[a] From experiments by the author.

These analyses show the part that methane can play in furnishing the carbon monoxide of afterdamp. When the methane content in mixtures of methane and air exceeds 9.5 per cent, products of incomplete combustion form. The reaction for complete combustion is: $CH_4 + 2O_2 = CO_2 + 2H_2O$.

COMPOSITION OF AFTERDAMP COLLECTED BY MEANS OF AN AUTOMATIC SAMPLER, 0.37 SECONDS AFTER DUST EXPLOSION IN EXPERIMENTAL MINE OF THE BUREAU.[a]

Gas.	Per cent.
Carbon dioxide (CO_2)	9.6
Oxygen (O_2)	1.0
Ethylene (C_2H_4)	.5
Carbon monoxide (CO)	9.6
Methane (CH_4)	2.4
Hydrogen (H_2)	5.5
Nitrogen (N_2)	71.4
Total	100.0

[a] Analysis by the author.

This analysis shows the large amount of carbon monoxide in afterdamp immediately after an explosion, before dilution with air from other parts of the mine.

COMPOSITION OF AFTERDAMP OBTAINED IN A COAL MINE ON THE DAY AFTER AN EXPLOSION IN THE MINE.[a]

Gas.	Per cent.
Carbon dioxide (CO_2)	1.5
Oxygen (O_2)	18.3
Carbon monoxide (CO)	.6
Methane (CH_4)	1.3
Hydrogen (H_2)	.3
Nitrogen (N_2)	78.0
Total	100.0

[a] Analysis by the author.

This sample is typical of afterdamp atmosphere, a few hours or even days after an explosion or a mine fire. Lights burn in such an atmosphere and give no warning of the presence of the deadly carbon monoxide.